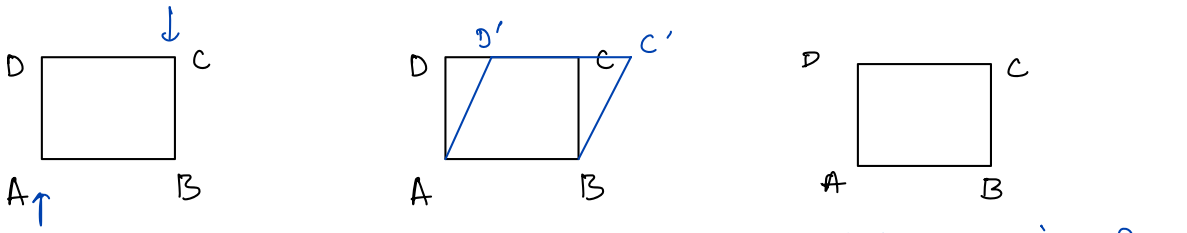
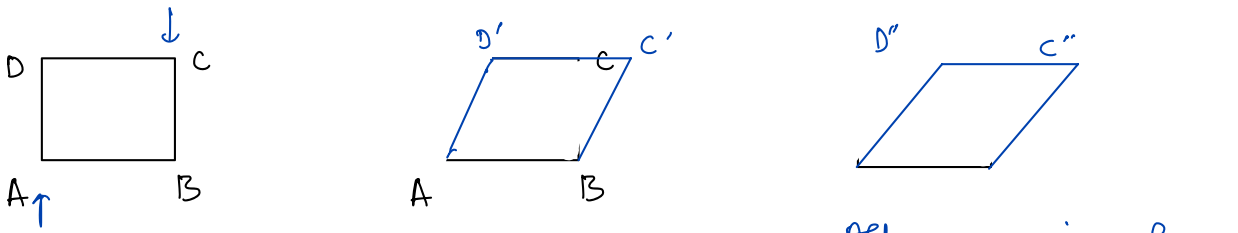
INTRODUCTION TO FLUID MECHANICS (GATE ONLY)

The branch of Science and Engineering which deals with the study of behaviour of fluid when it is at rest, at motion, forces causing flow & influencing its characteristics is called as "FLUID MECHANICS".

- Matter
  - Solids → Metals, Wood etc
  - Fluids
    - Liquids [Water, oil, Gases]
    - Gases [Air & all other Gases]

Solids try to comeback to original position after releasing force.





Fluids: Fluid has the ability to flow (deformation) & forget about its origin [original position]

SOLID: The matter which comprises in a given volume strictly with large number of molecules having strong attractive forces [cohesive forces] b/w them and have rigid and compact shape with fixed volume considered SOLIDS.

FLUIDS: A substance which is capable of flowing that deforms continuously undergo dynamic deformation when subjected to shear stress [even very small it is] are considered as Fluids which constitutes liquids & Gases.

LIQUIDS: A fluid which possess a definite volume and carry shape of container [in which it is filled]

→ In the same given volume, it contain relatively less molecules [than solids] & cohesive forces.

GASES: A fluid which is compressible & possess no definite volume & shape but it expands volume or compress volume wrt container volume is Gas.

GAS: Less molecules in given volume & in continuous random motion

∴ Less Attractive forces.

→ Solids show static deformation & have elastic nature

→ Fluids show dynamic deformation & have viscous nature

→ Those materials which possess both viscous & elastic nature, neither solid, nor fluid called as viscoelastic material.

Example: Flubber, Human skin, Volcanic Lava, Memory foam

FLUID MECHANICS

- Fluid Statics: Study of fluids at Rest
- Fluid Kinematics: Study of fluids in motion without considering forces causing motion
- Fluid Dynamics: study of fluids in motion by considering Forces causing motion
  - → Energy Equation
  - → Momentum Equation.

FLUID PROPERTIES

1. Pressure: The force or compressive stress on the fluid always perpendicular to the axis per unit area

$$P = \frac{\text{Force}}{\text{Area}} = \frac{\text{Normal force}}{\text{Area of surface}}$$

Pressure → Fluids → Always perpendicular direction

Stress → Solids → Acts any direction (⊥lar, parallel, axial, tangential)

INTERNAL PRESSURE has magnitude zero.

Dimensional Formula: M L T → time
↙ Mass ↓ Length
} Independent Parameters

$$P = \frac{\text{Force}}{\text{Area}} = \frac{F}{L^2} = \frac{MLT^{-2}}{L^2} = ML^{-1}T^{-2}$$

↓
Dimensional formula for pressure.

UNITS:

$$P = \frac{F}{A} \quad F \to N, \quad A \to m^2$$

$F = M \cdot (\text{acceleration})$

↓

$Kg - \frac{m}{sec^2}$

$$1\ \frac{Kg \cdot m}{sec^2} = N$$

$\therefore$ N/m^2 or N/cm^2 or N/mm^2

$1\ N/m^2 = 1\ Pa$: Pascal.

$1\ KPa = 10^3\ Pa$
$1\ MPa = 10^6\ Pa$
$1\ GPa = 10^9\ Pa$
$1\ N/cm^2 = 10^4\ N/m^2$
$1\ N/mm^2 = 10^6\ N/m^2$

1 atm = 101325 Pa

= 101.325 KPa

1 Bar = 10^5 Pa ≈ 100 KPa

1 Torr = 1 mm of Hg = $\rho_{Hg} \times g \times h$

= 13600 × 9.81 × 0.001

= 133.416 Pa

↓ Barometer unit

Pressure due to 1 m of Water head

$P = \rho_w \cdot g \cdot h_w$

$= 1000 \times 9.81 \times 1$

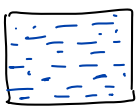
$P = 9810$ Pa

OTHER UNIT : $\frac{1 \text{ Kg.f}}{\text{Cm}^2} = \frac{1 \times 9.81}{10^{-4}} = 9.81 \times 10^4$ Pa

Kg-f : Kilogram force : force due to 1 Kg mass

2. Mass Density : ρ

Mass of matter occupied in unit volume at standard temperature & pressure



$\rho = \frac{\text{Mass}}{\text{Volume}}$ Kg/m³, g/cc } UNIT

Dimensional formula : $ML^{-3}T^0$ (or) ML^{-3}

$\rho_w = 1000$ Kg/m³ = 1 g/cc

$\rho_{Hg} = 13600$ Kg/m³ = 13.6 g/cc

$\rho_{air} = 1.2$ Kg/m³

$\rho \propto P$

$\rho \propto \frac{1}{\text{Temp}}$

$\rho \propto \frac{1}{V}$

$\rho = \frac{m}{V} = \frac{P}{RT}$

R : Ideal Gas constant

: 0.0821 atm/mole

3. Specific Volume : $V_S = \frac{1}{\rho} = \frac{Vol}{Mass}$ $\frac{m^3}{kg}$

Reciprocal of Mass density $(M^{-1}L^3)$

→ Related to Gases

→ Volume occupied by 1Kg Mass

4. Specific weight : (Weight density)

γ (or) $W = \rho g = \frac{W}{V}$

- Weight of Matter per unit volume

Units : N/m^3 , Dimensional Formula : $ML^{-2}T^{-2}$

$\gamma_w = 9810\ N/m^3$, $\gamma_{Air} = 11.77\ N/m^3$

$= 9.81\ KN/m^3$

5. Specific gravity : (Relative density) : S or G

Ratio of mass density of any matter to the mass density of standard fluid

$$G = \frac{\text{Density of Any matter}}{\text{Density of standard fluid}}$$

$$= \frac{\rho}{\rho_w} \quad \text{or} \quad \frac{\rho}{\rho_{air}}$$

Std. fluid

Liq : Water

Gases : Air

$$G = \frac{\text{Wt density of fluid}}{\text{wt density of water (or) Std. fluid}} = \frac{\gamma}{\gamma_w} = \frac{\rho \cdot g}{\rho_w \cdot g} = \frac{\rho}{\rho_w}$$

$G_w = 1$

$G_{Hg} = 13.6$

$G_{wood} = 0.6$

$G_{Air} = 0.001$

Using specific Gravity :

$\rho_{fluid} = G \times \rho_{std\ fluid}$

Fluid

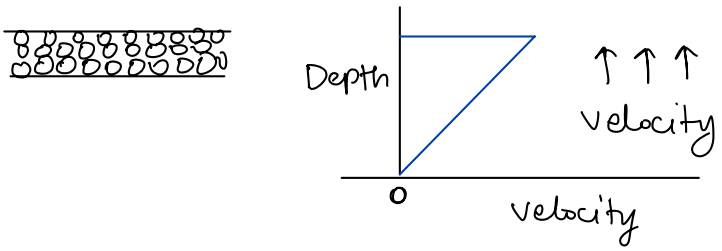
$= G \times \rho_w$

Fluid

Relative Density: Ratio of Density of any 2 fluids

Not mandatory: Std fluid

6. Viscosity: [Dynamic viscosity] : μ



- The internal resistance offered by the one fluid layer over the other to resist the movement due to molecular exchange & cohesive forces b/w molecules is VISCOSITY
- The property which measures resistance of flow i.e. resistance to shear (Angular) deformation is viscosity

Newton's law of viscosity:

Shear stress $\propto$ Rate of shear strain

[Angular deformation Rate]

(or) Velocity Gradient of fluid.

$$\tau \propto \frac{d\theta}{dt}$$

$$\propto \frac{du}{dy}$$

$$\left.\begin{array}{l}\\\\\end{array}\right\} \frac{d\theta}{dt} = \frac{du}{dy}$$

Take proportionality constant $\rightarrow \mu$

(Dynamic viscosity)

$$\tau = \mu \cdot \frac{d\theta}{dt}$$

or

$$\tau = \mu \cdot \frac{du}{dy}$$

$$\frac{F}{A} = \mu \frac{du}{dy}$$

Shear force:

$$F = A \cdot \mu \cdot \frac{du}{dy}$$

Dyn. Viscosity:

$$\mu = \frac{\tau}{du/dy} \text{ or } \frac{\tau}{d\theta/dt}$$

μ = τ per unit rate of shear strain.

The amount of shear stress required to produce unit rate of angular deformation. is called as Coefficient of dynamic viscosity.

Dimensional formula : $MT^{-1}L^{-1}$

units : $\frac{N-S}{m^2}$

SI Units :

$$1\ \frac{N\cdot S}{m^2} = 1\ Pa\text{-}S = 1\ \frac{Kg}{m\text{-}sec}$$

CGS units :

$$1\ \frac{Dyne\text{-}Sec}{cm^2} = 1\ Poise = 1\ \frac{g}{cm\text{-}sec}$$

$$1\ \frac{Kg}{m\text{-}sec} = 10\ \frac{g}{cm\text{-}sec}$$

$$1\ \frac{N\text{-}S}{m^2} = 10\ Poise$$

μ (SI unit) = 10 x μ (CGS unit)

$$\mu = \frac{\tau}{du/dy} = \frac{F/Area}{(du/dy)}$$

$$= \frac{F/L^2}{\frac{1}{Time}} = F\,T\cdot L^{-2}$$

$\mu = MLT^{-2}\ T\ L^{-2}$

$(\mu = ML^{-1}T^{-1})$: Dimensional formula derived.

$\mu_{water} = 1.005 \times 10^{-3}$ Pa-s

$\mu_{Air} = 1.81 \times 10^{-5}$ Pa-s

μ_{water} : (50 - 55) μ_{air} @ 20°C

μ_{water} : 100 μ_{air} @ 0°C

In liquids: $\mu \propto \frac{1}{Temp}$

In Gases: $\mu \propto$ Temperature

T ↑

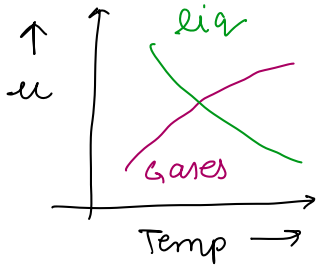
{ Gases becomes Dynamic }

Collision

Molecular moment ↑

∴ Cohesion ↑

∴ μ ↑



[μ : Independent of pressure]

7. Kinematic viscosity [ν]:

→ Ratio of dynamic viscosity to Mass density

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$$\nu = \frac{\mu}{\rho}$$

Dimensional formula: $L^2 T^{-1}$

units : m^2/sec or cm^2/sec

1 cm^2/second = 1 stoke

1 m^2/sec = $10^4 \frac{cm^2}{sec}$ = 10^4 stoke

1 cm^2/sec = 100 $\frac{mm^2}{sec}$

thus, $\frac{1\ mm^2}{sec}$ = 1 centistoke.

$\nu_{water} = 10^{-6}\ m^2/s = 1\ mm^2/s$

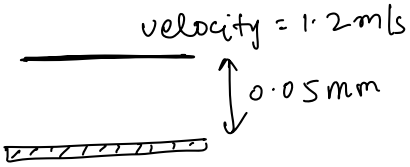
$\nu_{air} = 15 \times 10^{-6}\ m^2/s = 15\ mm^2/sec$

$\therefore \quad \nu_{air} = 15\ \nu_{water}$

Question

A plate 0.05 mm distant from a fixed plate moves at 1.2 m/s and requires a shear stress of 2.2 N/m² to maintain this velocity. Find the viscosity of the fluid between in the plates.

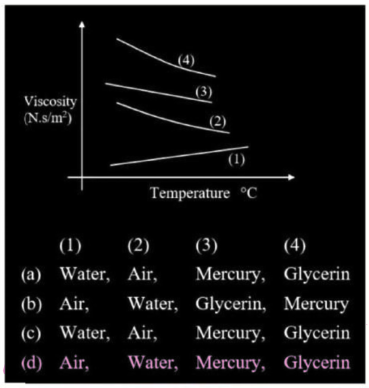
Solution:



$\tau = 2.2\ N/m^2$

$\mu = \dfrac{\tau}{\frac{du}{dy}} = \dfrac{2.2}{1.2/0.05 \times 10^{-3}} = 9.16 \times 10^{-5}\ \dfrac{N-s}{m^2}$

The graph shows the Viscosity of common fluid as a function of temperature



	(1)	(2)	(3)	(4)
(a)	Water,	Air,	Mercury,	Glycerin
(b)	Air,	Water,	Glycerin,	Mercury
(c)	Water,	Air,	Mercury,	Glycerin
(d)	Air,	Water,	Mercury,	Glycerin

1 is rising thus air.

lowest resistance of flow: water

thus 2: water

Mercury < Glycerin

(Hg) thus option (d)

For a fully developed flow between two parallel flat plates, the velocity gradient at a point is found to be 1000 s-1. If the relative density of the fluid is 0.88 and kinematic viscosity of the fluid is 0.74 centistoke, the shear stress at the same point is approximately:

(a) 0 .15Pa (b) 1.30 Pa

(c) 0.35 Pa (d) 0.65 Pa

$\dfrac{du}{dy} = 1000$ Take it as G

Relative density = 0.88

$\rho_w = 0.88 \times 1000 = 880\ kg/m^3$

$\nu = 0.74 \times 10^{-3} \times 10^{-6}\ m^2/s$

thus,

$\tau = 1000 \times 880 \times 0.74 \times 10^{-9} = 0.65\ Pa$

A cubical block of side 0.4m slides on an oiled (viscosity=8poise) plane horizontal surface. The oil film between the block and the cube surface has a uniform thickness of 0.4 mm. What force is required to drag the block at 4 m/s?

(a) 1.28 kN (b) 1.64 kN

(c) 1.92 kN (d) 2.56 kN

block: 0.4m

viscosity (μ) = $0.8\ \dfrac{N-s}{m^2}$

$y = 0.4mm$

$u = 4m/s$

$\tau = \dfrac{u}{0.4 \times 10^{-3}} \times 0.8 = 8 \times 10^{+5}\ N/m^2$

$F = 8 \times 10^5 \times 0.16$

$= 1.28\ KN$

A lubricated shaft rotates inside a concentric sleeve (Journal) bearing at 1200 rpm. The radial clearance is 0.1 mm and diameter of the shaft is 40 mm and its length in contact with oil sleeve is 60 mm and dynamic coefficient of viscosity of oil is 0.2 N-s/m².
Find the shear stress acting over the surface in kN/m².

$$1200 \text{ rpm} = \frac{1200 \times 2\pi \times 20\times10^{-3}}{60}$$

$$u = 2.51 \text{ m/s}$$

$$\text{viscosity} = 0.2, \quad y = 0.1 \text{ mm}$$

$$\left\{ \tau = \frac{2.51}{0.1} \times 10^3 \times 0.2 = 5.02 \text{ kN/m}^2 \right\}$$

The velocity distribution for flow over a plate is given by $u = 0.5y - y^2$ where 'u' is the velocity in m/s at a distance 'y' meter above the plate. If the dynamic viscosity of the fluid is 0.9 Ns/m², then what is the shear stress at 0.20 m from the boundary?

(ESE – 05)

(a) 0.9 N/m² (b) 1.8 N/m²
(c) 2.25 N/m² (d) 0.09 N/m²

$$u = 0.5y - y^2$$

$$\frac{du}{dy} = 0.5 - 2y$$

$$\frac{du}{dy} @ 0.20\text{m}$$

$$\mu = 0.9 \frac{\text{N-s}}{\text{m}^2} \left(\frac{du}{dy} = 0.1 \right)$$

$$\tau = \mu \frac{du}{dy} = 0.9 \times 0.1 = 0.09 \text{ N/m}^2$$

The velocity distribution in a laminar flow adjacent to a solid wall is given by $u = 3.0 \sin(5\pi y)$. The viscosity of the fluid is 5 poise. What is the shear stress at a section (i) y = 0.05m; (ii) y = 0.1m?

(a) 16.7N/m² and 6.1 N/m² **ESE - 2014**
(b) 33.4 N/m² and Zero
(c) 16.7 N/m² and 12.3 N/m²
(d) 16.7 N/m² and Zero

$$u = 3.0 \sin(5\pi y)$$

$$\frac{du}{dy} = 15\pi \cos(5\pi y) = 15\pi \cos(5\pi y)_{\downarrow 180^\circ}$$

a) $y = 0.05$:

$$\tau = 0.5 \left[15\pi \cos(5 \times 180 \times 0.05 \right]$$

$$= 16.67 \text{ N/m}^2$$

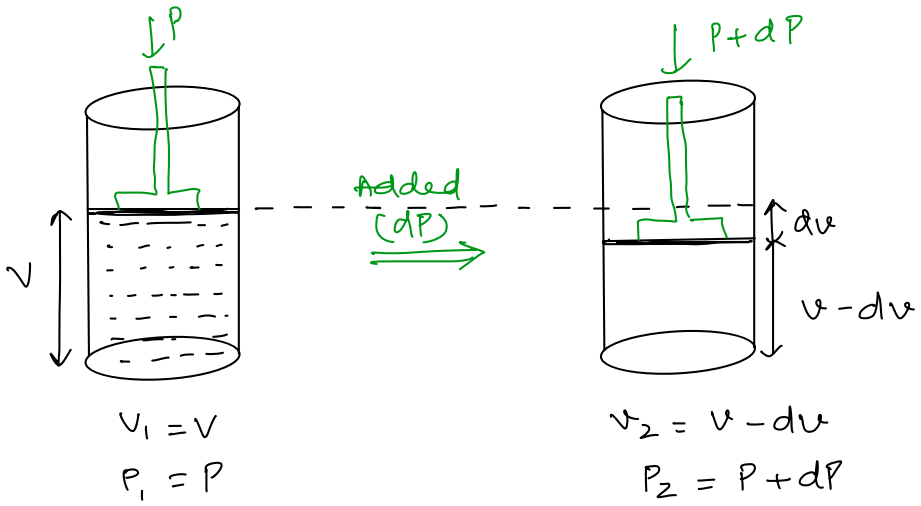
b) $y = 0.1$ m:

$$\tau = 0.5 \left[15\pi \cos(5 \times 180 \times 0.1) \right]$$

$$= 0 \text{ N/m}^2$$

7. Bulk Modulus of Elasticity:

[Coefficient of compressibility]



$V_1 \longrightarrow V_2$

Stress Applied $\equiv dP$ [Additional Presswre]

Strain caused in **volume** : Volumetric strain

$$\frac{\text{change in volume}}{\text{original volume}} = \frac{dV}{V}$$

Bulk modulus of elasticity

$$= \frac{\text{Compressive stress}}{\text{Volumetric strain}}$$

$$K = \frac{dP}{-\frac{dV}{V}} = \frac{(P_2 - P_1)}{\left(\frac{V_2 - V_1}{V_1}\right)} = \frac{\Delta P}{\left(\frac{\Delta V}{V}\right)}$$

'$-$' sign Shows compression

- The amount of incremental pressure 'dP' required for the decrease of volume of a gas by a amount of [dV] is called bulk modulus of elasticity (or) Coefficient of compressibility (K)

Mathematically, The ratio of compressive stress to volumetric strain is K.

Units : N/m^2 or Pa

Considering ρ of Gas:

$$K = \rho \cdot \frac{dP}{d\rho}$$

→ compressibility : β

Reciprocal of bulk modulus.

→ $K \propto$ Pressure

$K \propto$ Temperature (Gases)

$K \propto \frac{1}{\text{Temp.}}$ (Liquids)

→ At NTP :

$K_{water} = 2.06 \times 10^9$ Pa

$K_{Air} = 1.03 \times 10^5$ Pa

$K_{steel} = 2.06 \times 10^{11}$ Pa

→ Compressibility :

$\beta_{Air} = 20000 \times \beta_{water}$

$\beta_{water} = 100 \times \beta_{Steel}$

→ For system of Gases.

A. Constant Pressure : $dp = 0$ $\therefore K = 0$

B. Constant Volume system : $dV = 0$ $\therefore K = \infty$

C. Isothermal bulk modulus : $K_{ISO} = P$

[Temp Constant]

D. Adiabtic Bulk Modulus : $K_{adia} = \gamma \cdot K_{iso}$

↓

Adiabatic index

(1.4) If not given

→ Bulk Modulus gives velocity of pressure waves.

$$C = \sqrt{\frac{K}{\rho}} = \sqrt{\gamma RT}$$: For adiabatic

↓ 1.4 ↓ Temp (in K)

↓ constant

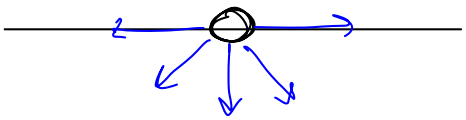
$$\text{Mach number} = \frac{\text{Velocity of fluid}}{\text{velocity of sound}} = \frac{v}{c}$$

$$c = \sqrt{\gamma RT} = 343 \text{ m/s}$$

$$v = \frac{1100 \times 1000}{3600} = 305.55 \text{ m/s}$$

$$M = \frac{305.55}{343} = 0.9$$

SURFACE TENSION



Tension developed on surface of water is is Surface tension.

Cohesion: Attraction between molecules of similar kind

Adhesion: Attraction between different molecules (Air & water)

- The phenomena of measure of liquid's tendency to take a spherical shape caused by mutual attraction of liquid molecules and that exert tension at the surface of fluid called as "surface tension"
- A molecule which is completely immersed inside the liquid, surrounded by equal number of molecules by cohesive forces of attraction and net force acting on the molecule is zero.
- If the molecule is located on surface of fluid, now it is under influence of attractive force b/w same liquid mol. (cohesion) & also with the air & Gas molecules above it [adhesion].

But attraction b/w same molecules are stronger due to chemical bonding, so cohesion > adhesion.

resulting in tension induced by Net vertical downward force and also due to molecules adjacent (left & right) to

it.

∴ Surface tension is caused due to Cohesion b/w particles at the surface of liquid

→ Mathematically, a) Tension per unit length (N/m)

b) Energy per unit area of interface (J/m^2)

Dimensional formula: (MT^{-2})

c) Work done per unit Area

d) Force per unit length of surface

1) Instrument: · Tensiometer
· Stalagnometer

2) Water–Air Interface : 0.0736 N/m @ 20°C

3) $ST \propto \frac{1}{Temp}$

$\propto \frac{1}{Impurity\ Conc.}$

4) No effect of pressure on ST

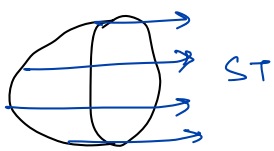
5) ST of water is zero at critical point

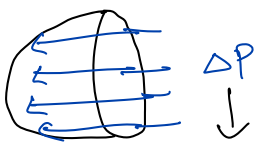
T = 647 K

P = 22.06 MPa

* ST on different molecules:

1. Liquid Droplet:



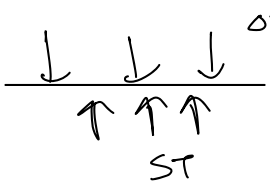


Patm = 101.3 KPa

P = 104.3 KPa

(ΔP = 3 KPa)

[additional Gauge pressure other than Patm]



At equilibrium

ST Force = Pressure Force

ST: Acts along circumference

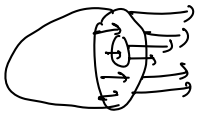
ΔP: Acts on Area

For liquid droplet: $F_{ST} = F_{\Delta P}$

$$\sigma(\pi d) = \Delta P\left(\frac{\pi}{4}d^2\right)$$

$$\left\{\Delta P = \frac{4\sigma}{d}\right\}$$

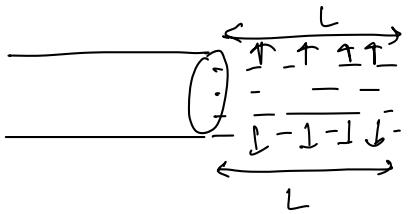
2. Soap bubble:



$$\sigma \cdot 2\pi d = \Delta P \cdot \frac{\pi}{4} d^2$$

$$\therefore \left\{\Delta P = \frac{8\sigma}{d}\right\}$$

3. Liquid jet:



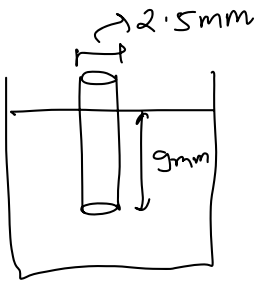
$$\sigma \cdot 2L = \Delta P\,(dL)$$

$$\therefore \left\{\Delta P = \frac{2\sigma}{d}\right\}$$

A glass tube of 2.5 mm internal diameter is immersed in oil of mass density 940 kg/m³ to a depth of 9 mm. If a pressure of 148 N/m² is needed to form a bubble which is just released, what is the surface tension of the oil? **(ESE-18)**

(a) 0.041 N/m (b) 0.043 N/m

(c) 0.046 N/m (d) 0.050 N/m



$P = \rho g h$

$= 940 \times 9.81 \times 9 \times 10^{-3}$

$P_{int} = 83\,Pa$

$P_{ext} = 148\,Pa$

$\Delta P = 148 \cdot 83 - 83$

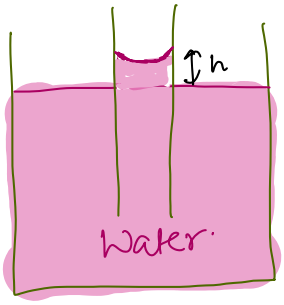
$\Delta P = 65\,Pa$

* GOOD QUESTION

$$\Delta P = \frac{4\sigma}{d}, \quad 65 = \frac{4\sigma}{2.5 \times 10^{-3}}$$

$$\{\sigma = 0.041\ N/m\}$$

10. Capillarity:



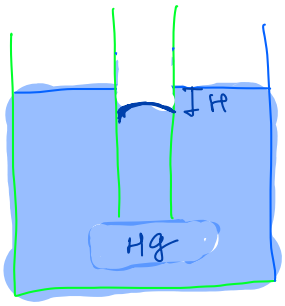
- Water wetted on surface
- Concave upwards

$\theta < 90°$

Capillary Rise

(Adhesion > cohesion)

Ex: Water.



: CAPILLARY FALL

(Cohesion > Adhesion)

Not wetted case

Concave down case, $\theta > 90°$

* The phenomenon of rise or fall of a liquid surface relative to the adjacent general level of liquid in small diameter tubes, is called as capillarity.

→ Capillarity is due to cohesion & Adhesion

→ The curved free surface of liquid is called as Meniscus

$$\text{Capillary Height, } h = \frac{4\sigma\cos\theta}{\rho g d}$$

If its happening in water

$\sigma = 0.075$

$\gamma = 9810$

$\theta = 0°$

$\cos\theta = 1$

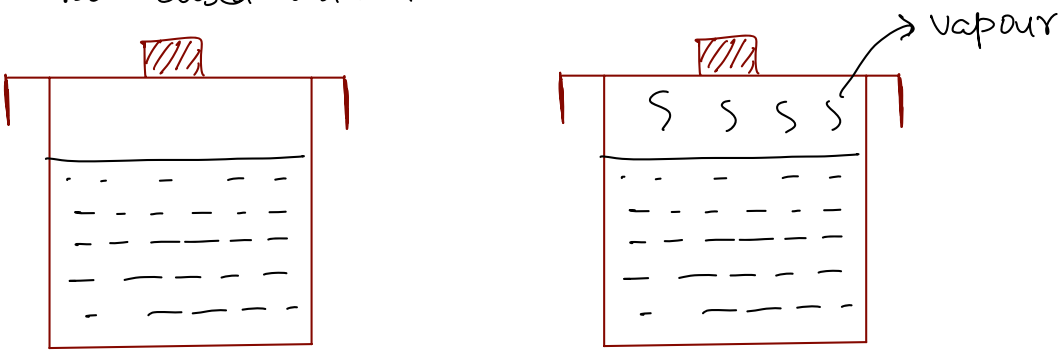
$$\equiv \boxed{h = \frac{0.3}{\gamma d}}$$

$$h \propto \frac{1}{\text{dia of tube}}$$

$$h \propto \frac{1}{\text{Density of fluid}}$$

11. Vapour Pressure :

vessel closed with lid



START BOILING

Temp↑

No of vapour molecules formed ≈ No of vapour converted to liquid drops

∴ Equilibrium

Pressure exerted by vapour on liquid surface → (VP)

The pressure at which liquid boils & is in equilibrium with its own vapour molecules is called as vapour pressure. When the air above liquid surface saturated with vapour molecules & then these vapour molecules return back to liquid surface exerting the pressure called as Vapour pressure.

"Hg" has a very low vapour pressure

thus excellent fluid to use in Barometer.

Volatile liquids like benzene etc. have high vapour pressure.

Cavitation:

Liquid

↓ Temp Rise till boiling point

↓ Reduce the (or) pressure to vapour pressure.

Vapour

Bernoulli's equation:

$$z + \frac{P}{\rho g} + \frac{v^2}{2g} = \text{Constant}$$

- z → Datum Head
- $\frac{P}{\rho g}$ → Pressure head
- $\frac{v^2}{2g}$ → velocity head

$$\frac{P_1}{\rho g} + \frac{v_1^2}{2g} = \frac{P_2}{\rho g} + \frac{v_2^2}{2g}$$

- The phenomena at which a liquid may boil even at ordinary temperature, if pressure above liquid surface is $\leq VP$ is called as CAVITATION

Local pressure drops to (vapour pressure.)

Cavitation caused due to:

a) Reduction of local pressure to a limiting value [VP]

b) Increase of Elevation [Ambient pressure is less]

c) Increase of velocity

→ when a liquid droplet converted to vapour bubble and later vapour bubble collapses forming a cavity on pipe wall, this phenomena of formation & collapse of vapour is called as cavitation.

The damage of surfaces & their action due to vapour bubble collapse is called as Pitting Action

Cavitation results in:

- Erosion of pipe walls, blades of turbine, Parts of Machine
- Vibration & Noise
- Fatigue Failure
- Reduction in Efficiency

Cavitation is observed in:

- Turbine Runner exit
- Pump Suction Pipes
- Impellers
- Syphon pipes
- Spillway & Sluice way Gates.
- CORNERS, BENDS & constricted sections.

Cavitation Number: $\sigma_c = \dfrac{P - P_v}{\rho V^2/2}$

$\dfrac{\rho V^2}{2}$: Dynamic Head

P : Local pressure on liquid

P_v : Vapour Pressure of liquid

To resist cavitation: Use the materials of rubber, Alloys of Aluminium, Bronze, Stainless Steel etc.

Look ESE 2003 questions

TYPES OF FLUID

Perfect fluids

Ideal Fluids
(Does not exist)

- Non viscous, Frictionless
- Incompressible, Zero ST
- → $\mu = 0$, $\tau = 0$
- → uniform velocity Distribution [Rectangular]

Real fluids

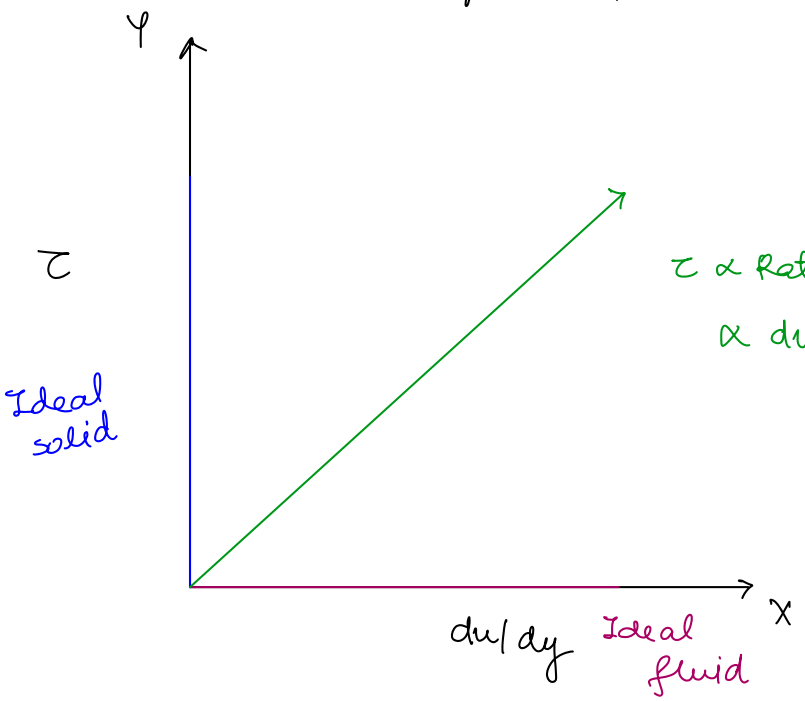
Newtonian Fluids
Satisfy Newton's law of viscosity

$$\tau = \mu \cdot \frac{du}{dy}$$

Ex: water, Petrol, Diesel, Gasolene light oils, kerosene

Non-Newtonian Fluids
- Does not obey Newton's law
- $\tau = A\left[\frac{du}{dy}\right]^n + B$

Ex: Blood, Milk, clay, lipstic, Tooth paste.



Non-Newtonian Fluids

Time Independent Fluids
'μ' doesnot depend on time.

- → Dilatant Fluid: Milk
  $B = 0$, $n > 1$, $\tau = A\left(\frac{du}{dy}\right)^n$
- → Pseudoplastic fluid: Blood
  $B = 0$, $n < 1$, $\tau = A\left(\frac{du}{dy}\right)^n$

Time Dependent Fluids
μ Depends on time

- $(n < 1)$ → Thixotropic Fluid: $\mu \propto \frac{1}{t}$
  ex: Lipstick
- $(n > 1)$ → Rheotropic fluids: $\mu \propto t$ } Gypsum in Water

→ Bhingum plastic : Toothpaste

$n=1$, $B \neq 0$, $\tau = A \frac{du}{dy} + B$

Non- Newtonian fluids: The fluids that doesnot obey Newton's law of viscosity are called as Non- Newtonian Fluids

→ The study of Non - Newtonian fluids is called as RHEOLOGY

→ Equation for Non - Newtonian fluids :

$$\tau = A \left[\frac{du}{dy} \right]^n + B$$

A : Flow consistency index

τ_y ← B : Flow behaviour Index (Min yield stress to start flow (Deformation)

$$\tau = A \left[\frac{du}{dy} \right]^n + \tau_y$$

If a fluid shows, No need of Min Yield Stress τ_y (or) $B = 0$

Exponent = 100% = 1 → n

Completely flow consistency based on viscosity

$\therefore A = \mu$

Now equation is

$$\tau = \mu \left[\frac{du}{dy} \right]$$: Model is Newtonian Fluid.

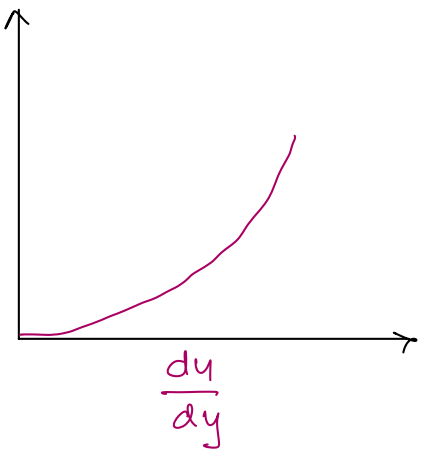
1. Dilatant Fluids: Shear thickening Fluids

$B = 0$, $n > 1$ $\quad \tau = A \left[\frac{du}{dy} \right]^n$ [Butter, Starch sol^n, Sand suspension]

$$\tau = A \left[\frac{du}{dy} \right]^{n-1} \left[\frac{du}{dy} \right]$$

$$\tau = \mu_{app}\left[\frac{du}{dy}\right]$$

Apparent viscosity $\leftarrow \left\{ A\left[\frac{du}{dy}\right]^{n-1} \right\}$

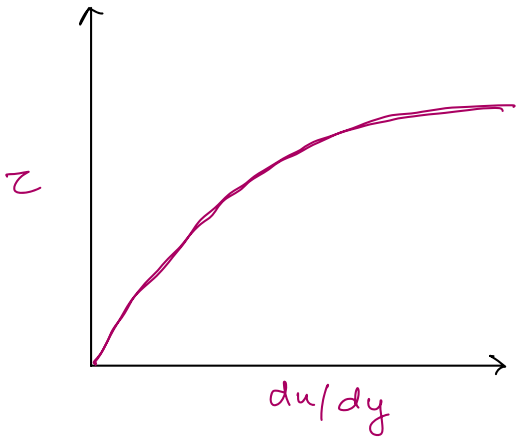


2. Pseudo plastic Fluids: $n < 1$, $B = 0$

Shear thinning fluids

Ex: Paper pulp, Blood, Paints, Suspension of polymers

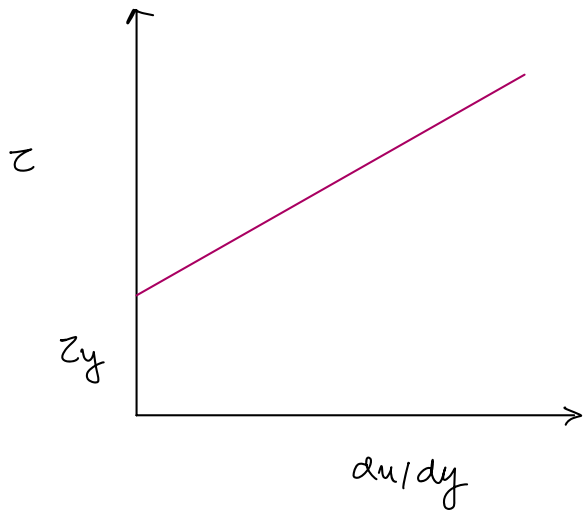
" " Rubbers



3. Bingham plastic fluids: $n = 1$, $B > 0$

(τ_y exist)

$$\tau = \mu_{app}\left(\frac{du}{dy}\right) + \tau_y$$

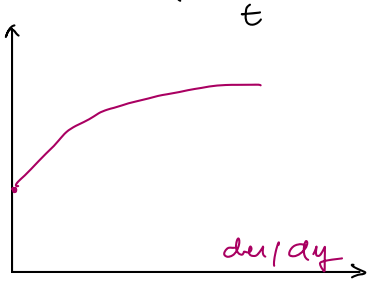


Ex: Sewage Sludge, Tooth Paste, Drilling Mud, clay.

4. Thixotropic [Plastic] Fluids: $B > 0$, $n < 1$, $\mu \propto \frac{1}{t}$

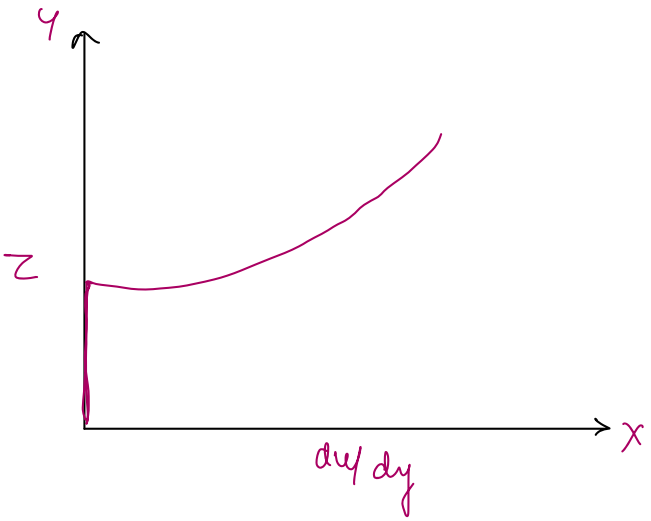
Example: Lipstick, Printers Ink.

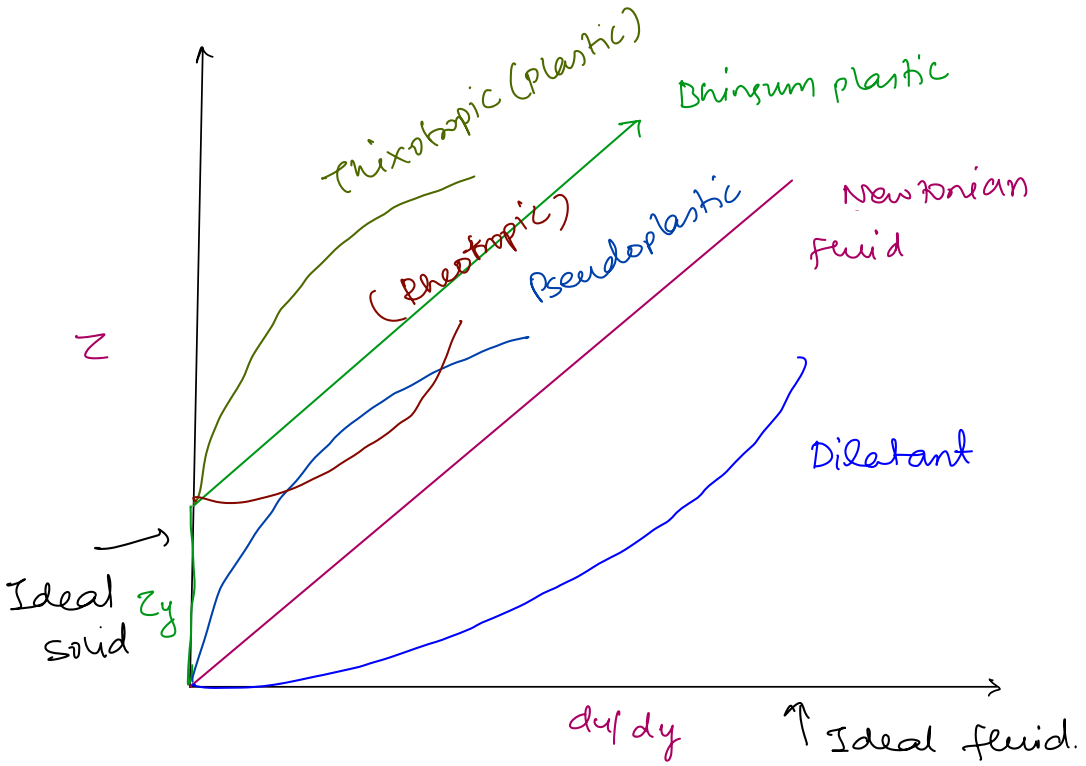
$n > 1$	$n < 1$
Less increase of τ	High increase of τ
High increase of du/dy	Less increase of du/dy



5. Rheotropic or Ideal plastic: $n > 1$, $B > 0$

$u \propto t$





Shear stress is proportional to RATE of shear strain.

$\begin{cases} n > 1 : \text{Dilatant} \\ n < 1 : \text{Pseudoplastic} \end{cases}$

In an experiment, the following shear stress-time rate of shear strain values are obtained for a fluid;

Shear Strain rate (1/s):	0	2.0	3.0	4.0
Shear stress (kPa) :	0	1.4	2.6	4.0

How can the fluid be classified? **(ESE-08)**

(a) Newtonion fluid

(b) Bingham plastic

(c) Pseudo plastic

(d) Dilatant.

Sol: No linear variation: Non-newtonian

No yield stress : b x

τ : increases high

$\frac{du}{dy}$: decreases less

$n < 1$ (c)

In an experiment to determine the rheological behavior of a material, the observed relation between shear stress, τ, and rate of shear strain, $\frac{du}{dy}$, is $\tau = \tau_0 + c\left(\frac{du}{dy}\right)^{0.5}$. → $n < 1$

The material is **(ESE-11)**

(a) A Newtonian fluid

(b) A thixotropic substance

(c) A Bingham plastic

(d) An ideal plastic

Assertion (A): In non-Newtonian fluids, the shear stress at any point is not a linear function of normal distance from the surface — True

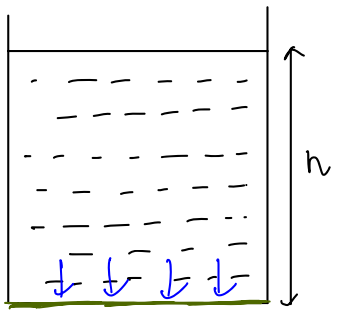
Reason (R): This behavior usually arises because the fluid molecules are very large, like polymers or proteins (ESE 11 ME) — True

A.

{INVISCID, $\mu = 0$}

FLUID STATISTICS

The study of fluid behaviour when a force or pressure acting on it when the fluid is at rest is called as Fluid statics.



Normal force acting on the base

$$\text{Pressure} = \frac{F}{A} = \frac{m \cdot a}{A} \quad (a \to g)$$

$$\text{Mass} = \rho V = \rho \cdot A \cdot h$$

$$\text{Pressure} = \frac{\rho A h g}{A} = \rho g h.$$

or

(γh) : unit weight x height

- The normal force exerted by a static fluid per unit area is pressure.

UNITS: N/m^2 (or) Pa.

γ : unit weight of given fluid.

- If the exerting pressure is same but fluids are different, then height of fluid column varies.

Pressure: 10KPa

water : $P = \rho g h$

$10000 = 1000 \times 9.81 \times h_w$

$h_w = 1.019\ m$

Hg: $10000 = 13600 \times 9.81 \times h_{Hg}$

$h_{Hg} = 0.075\ m$

If pressure same:

$\rho_1 g h_1 = \rho_2 g h_2$

$\boxed{\rho_1 h_1 = \rho_2 h_2}$

$\boxed{S_1 h_1 = S_2 h_2}$

Specific gravity

TYPES OF PRESSURE

1. Absolute zero: The point below which, any molecular activity ceases.
   - Pressure exerted by absolute vacuum.
   - Temp at absolute zero $\longrightarrow$ $-273°C$ / $0\ K$.
2. Standard Atmospheric pressure: Patm

   Pressure exerted by atmospheric air on surface of a fluid is atmospheric pressure.

   → Measured using Barometer.

   → Mean sea level (MSL): 19 years average height of tides

$Patm = 760mm\ of\ Hg$

$= 10.3m\ of\ water$

$= 101.03\ kPa$

$= 1\ bar$

$Patm \rightarrow \rho_{Hg} \cdot g \cdot h_{Hg} = 13600 \times 9.81 \times 0.76 = 101.396\ kPa$

$= 1.013\ bar$

$P_{atm} \rightarrow \rho_w \cdot g \cdot h_w = 1000 \times 9.81 \times 10.3$

$= 101.043$ KPa

$= 1.0104$ bar ≈ 1 bar

3. Local atmospheric Pressure: P_{atm} measured at given location

[Either above MSL or Below MSL]

Varies from location to location

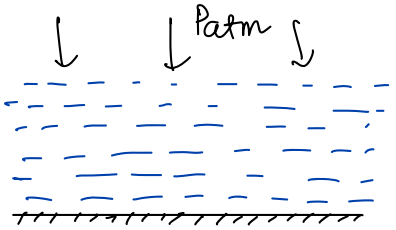
4. Absolute Pressure: Accurate pressure measured by considering all pressure of a location

$P_{abs} = P_{atm} \pm P_{Gauge}$

↓

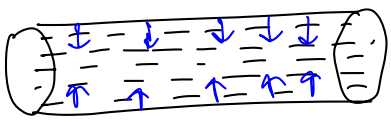
Local pressure

5. Local pressure / Gauge pressure:



$P_{abs} = P_{atm}$

$P_{gauge} = 0$



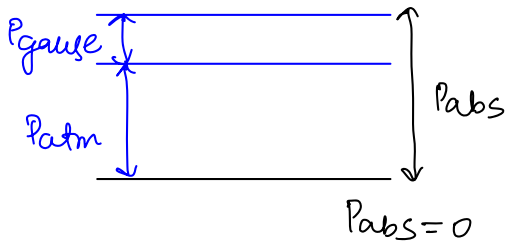
pressure induced by walls of container / pipe (ρgh)

(Local pressure)

*Based on elevation or location:

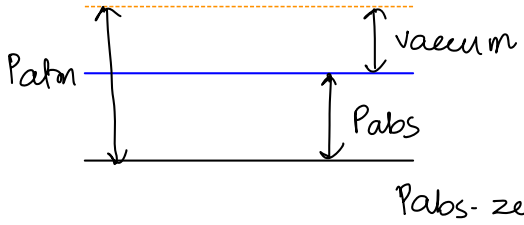
1. Elevation < MSL: $P_{abs} = P_{atm} + Gauge$

$= P_{atm} + \rho gh$



2. Elevation > MSL :

$$P_{abs} = P_{atm} - \rho g h$$
$$= P_{atm} - P_{Gauge}$$
$$= P_{atm} - \text{Vacuum Pressure}$$



Pabs - zero

Question: Gauge pressure @ bottom of 50m deep lake?

$$P_G = \rho g h = 1000 \times 9.81 \times 50$$
$$= 490.5 \text{ KPa}$$

- If local atmospheric pressure is given then only that is used.

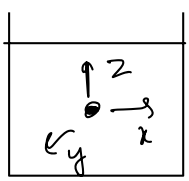
$$\{1 \text{ Bar} = 10^5 \text{ Pa}\}$$
$$1 \text{ mm of Hg} = 133.4 \text{ KPa}$$
$$1 \frac{\text{Kgf}}{\text{cm}^2} = 9.81 \times 10^4 \text{ Pa}$$

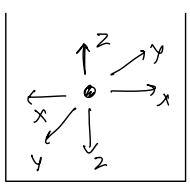
Hydrostatic law: The rate of increase of pressure in vertically downward direction in a static fluid is equal to specific weight of fluid at that point

$$dP = \rho g (dz)$$

$$\frac{dP}{dz} = \rho g, \quad \frac{dP}{dz} = -\gamma$$

→ vertically downward.



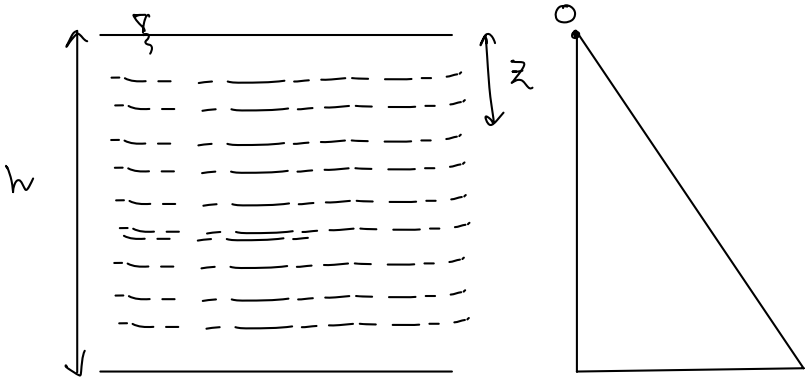


Applying Equilibrium of forces,

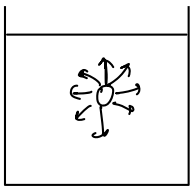
$$\Sigma F_x = 0 \quad : \quad \frac{\partial P}{\partial x} = 0$$
$$\Sigma F_y = 0 \quad : \quad \frac{\partial P}{\partial y} = 0$$
$$\Sigma F_z = 0 \quad : \quad \frac{\partial P}{\partial z} = -\gamma$$

(P) ↓ on

∵ static mass of fluid constant



PASCAL'S LAW:

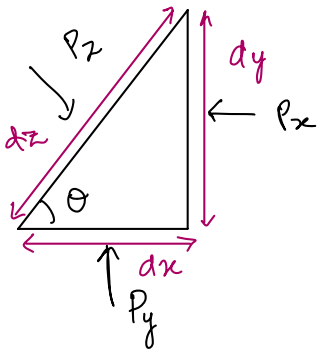


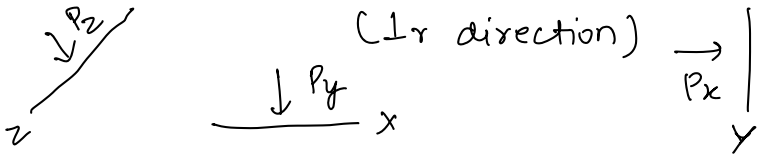
→ In static fluid, the pressure acting on a fluid molecule acts equally in all directions

→ Pressure applied on a confined fluid increases the pressure throughout same amount

→ A fluid element of dimensions dx, dy & dz with unit length experiences forces P_x, P_y & P_z

→ These are Normal forces (1r direction)





$F_x = P_x \cdot dy \cdot 1 = P_z \cdot dz \cdot 1 \cdot \sin\theta$: x component of P_z

$F_y = P_y \cdot dx \cdot 1 = P_z \cdot dz \cdot 1 \cdot \cos\theta$: y component of P_z

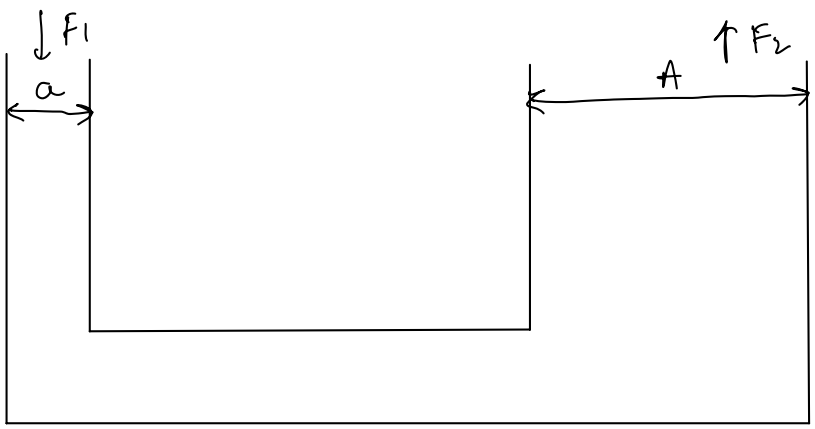
$dy = dz \sin\theta$

$dx = dz \cos\theta$

Thus, $\{ P_y = P_x = P_z \}$ PASCALS LAW PROVED

Application of Pascal's law:

1) Hydraulic Jack
2) " Lift
3) " Breaks
4) Dam
5) Water towers
6) Hydroelectric Power plant.



$F = P_1 \cdot a$

$W = P_2 \cdot A$

$P_1 = P_2$

$\frac{F}{a} = \frac{W}{A}$

Example: Force : 120N acts on area of piston $6m^2$ on the other end of piston, the area is enlarged to $10m^2$. Find the weight of object carrying by fluid?

Solution:

$$\frac{120}{6} = \frac{W}{10}$$

$$(W = 200N)$$

PASCALS LAW IS VALID FOR: [$\tau = 0$] condition for validity

1) Ideal fluids → Both At Rest & At motion.

2) Real fluids → At Rest [$\because$ vel = 0, $\tau = \mu \cdot \frac{v}{y} = 0$]

→ In motion with uniform velocity

[Rigid body motion] $du = 0$

$\tau = \mu \cdot \frac{du}{dy}$ → ($\tau = 0$)

Basic formula:

1) Power 'P' = Shear force x velocity

= $\tau \times A \times$ Velocity

2) Power $P = \frac{2\pi NT}{60}$ → Torque

↓

{Tangential Force x Radius of shaft}

As per pascal law, uniform velocity ≈ constant Acceleration

Static fluid : Positive normal stress & zero shear stress.

PRESSURE MEASUREMENT INSTRUMENTS :

- **Manometers**
  - **Simple**
    - a) Piezometer
    - b) U-Tube
    - c) Single column
      - vertical
      - Inclined
  - **Differential**
    - a) U-Tube
    - b) Inverted U-tube
- **Mechanical Gauges**
  - Used to measure high pressure but with less precision (accuracy)
    - → Bourdon's Gauge
    - → Bellow's Gauge
    - → Diaphragm Gauge.

- MANOMETERS:

The devices used to measure pressure at any point in the pipe or liquid column or water tank by height of liquid rise or by balancing the column of liquid by different kind of liquid is called as Manometer.

. Piezometer :

→ A Glass tube open at one end to atmosphere & another end connected at a point of pressure measurement in a pipe or in a vessel is said to be piezometer

→ The height upto which liquid rises in tube is called as pressure head [h] & pressure is estimated using ρgh or γh